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THE SPECTROSCOPY OF THE EXTREME ULTRA-VIOLET[1]

In the year 1914 I published a monograph under the title of "The Spectroscopy of the Extreme Ultra-Violet"; to-day I wish to trace the progress of the subject to the present time. The part of the spectrum with which we are concerned has for its less refrangible limit wave-length 2,000 A.U.; it now extends to a region separated from X-rays by less than 200 units.

It is more than thirty years ago since Victor Schumann led the way into this undiscovered country, and gave his name to the region he explored. His methods and his results are familiar to all spectroscopists, but it may be well to remind you of the nature of the difficulties which he conquered. The extension of the spectrum in the ultra-violet is opposed by three factors, the opacity of the materials usually employed in the making of prisms and lenses, the opacity of gelatine, and the opacity of the air. By the use of fluorite, by the invention of a special photographic emulsion and by placing his spectrograph in vacuum, Schumann demonstrated that the spectrum could be extended by nearly eight hundred units.

The result, though easily described, was only reached after years of patient toil, for experimentation in this region was, and still is, beset with great difficulties. Every contribution which Schumann made to the subject is marked by the greatest exactness and finish; his field was limited, but within that field not only his technique but also his reasoning remain a model to this day.

The first and most characteristic product of his labors was a series of exquisite spectrograms of hydrogen; but owing to the lack of a dispersion curve for fluorite, it was out of the question to attach wavelengths to the lines

[1] Address of the president of the American Physical Society, Toronto, December, 1921.

which constituted these spectra. It was obvious that if a concave diffraction grating could be substituted for the prisms and lenses wavelength measurements could be made and at the same time the limitations set by the opacity of fluorite could be avoided.

I attacked the problem a good many years ago and most of the results have been long since in print. The spectrum of hydrogen was extended to the neighborhood of 900 units and its wavelengths were measured to within an error 0.2 of a unit, the accuracy being checked by Wolff through an ingenious application of certain series relations devised by Paschen. In a fruitless search for substances more transparent than fluorite the opacity of a large number of solids was next tested. The absorption of the commoner gases was measured and it was demonstrated that oxygen partly resumed its transparency with decreasing wavelength, a result which has been recently confirmed as we shall presently see. A considerable time was spent in the study of the emission of various substances and in the measurement of their spectra; partly because they occurred as impurities in the hydrogen discharge and partly because of the interest which attached to certain series relations connecting the radiations of some of them.

Toward the end of the period covered by these researches W. T. Bovie[2] of the Harvard Medical School became interested in the abiotic effects of Schumann rays, and carried out several investigations in that field. At nearly the same time F. H. Palmer[3] conducted a study of the volume ionisation produced by ultra-violet light; his experiments afford what I believe is the most direct proof of the effect yet obtained by any one. Later P. E. Sabine[4] carried out a preliminary investigation of the photo-electric effect in the region of very short wavelengths; and I. C. Gardner[5] made a quantitative study of the reflective power of metals and demonstrated the superiority of platinum and silicon over speculum in the extreme ultra-violet.

[2] *Botanical Gazette*, 59, No. 2, 1915; 60, No. 2, 1915; 61, No. 1, 1916, etc., etc.

[3] *Phy. Rev.*, 32, p. 1, 1911.

[4] *Phy. Rev.*, N. S. 9, p. 210, 1917.

[5] *Astrophysical J.*, 45, p. 30, 1917.

Having completed a reconnaissance of the region discovered by Schumann it was natural that attention should turn to its extension toward the ultra-violet. By the use of helium gas and by the employment of a strong disruptive discharge I succeeded in pushing the spectral limit to the neighborhood of 500 AU in 1917.[6] In the process of this research various gas spectra including those of argon and nitrogen came under observation; moreover, the existence of the series in hydrogen predicted by Ritz and obeying the law $V = N\left(1 - \frac{1}{m^2}\right)$ was confirmed.

During the period whose activities have so far been described interest in the Schumann region had been confined to a very few, and the work had been carried on in but a limited number of places. We now enter on an epoch extending to the present time, where the study of this field bids fair to be much more general. In view of this awakening interest it may be well to pause long enough to say something of the technique which is involved in the study of the spectral region under discussion.

The spectroscopy of the extreme ultra-violet combines all the difficulties inherent in the nice adjustment of delicate optical apparatus with those which accompany the production and maintenance of high vacua in metallic containers of large volume. The first are only to be overcome by skill and patience; the second have been greatly alleviated during recent years by the improvement in mechanical vacuum pumps and by the use of charcoal and liquid air. In the design of the vacuum spectroscope, whether it be intended for prism or grating, simplicity is the chief requisite. This I was at some pains to point out years ago. A good example is afforded by the highly successful apparatus of Millikan where grating, plate holder and source are all contained in one cylindrical brass tube closed at the ends by simple plates made air tight with rubber gaskets. The improvements which McLennan has introduced have also been directed away from the pernicious ingenuities of the instrument makers.

[6] *Astrophy. J.*, 43, p. 89, 1916.
SCIENCE, 45, p. 187, 1917.

Time does not permit the discussion of details of design but it is useful to note that McLennan has emphasized the advantage of horizontal surfaces for those joints which must be often made and broken; I venture to add that I still find the gasket formed of a string of soft wax useful in such joints even when the highest vacuum is required. Moreover, I have found that a carefully cut screw of say ½ mm. pitch working in a nut about 6 cm. long will serve to communicate motion to electrodes within the apparatus without introducing a leak provided the screw and nut are sealed together with wax after each adjustment.

There is one fault in vacuum spectroscope design so common that it merits particular attention. It is concerned with the question of angular aperture in those cases where a lens cannot be employed. For example, if the slit is placed on the circle whose diameter is the grating's radius of curvature, and to which the plate should conform, it is mechanically difficult to place the source of light sufficiently near the slit to fill the grating. Millikan has overcome the trouble, as we have just seen, by placing the source of light within the body of the spectroscope, but this process presents some inconveniences when vacuum tube spectra are to be examined.

The grating affords the only means at our disposal for analyzing light of the very shortest wave lengths spectroscopically, but its use is accompanied by several disadvantages, not the least of which arises from the fact that an amount of tarnish which would be quite harmless in the ordinary part of the spectrum proves fatal in the region under discussion. To the favored few who have a ruling engine at their command the difficulty is overcome by the simple expedient of ruling a new grating! The majority are not so fortunate, they may therefore be interested in the results of some experiments of my own. Guided by the work of Gardner, I have tried covering a tarnished grating with a thin cathode deposit of either platinum or silicon. The results seem favorable and I have good hopes that the method affords a means of rejuvenating diffraction gratings especially if silicon be employed.

We may now return to a consideration of the results of the last half dozen years. In 1914, Saunders,[7] working at Tübingen, followed the spectra of calcium and zinc in a vapor lamp to the neighborhood of 1000 A.U. He also confirmed my observations on the hydrogen lines of the Ritz series.

About the same period L. and E. Bloch[8] began their investigations; their work, interrupted by the war, has recently been resumed. Their vacuum spectrometer contains a train of fluorite and includes the novel feature of a constant deviation prism. They have measured the spark spectra of sixteen elements, to the neighborhood of 1400 A.U. Their tables contain not only their own results but also those of other investigators in the same field. The determinations of wavelength rest on my values for certain lines in aluminium, hydrogen, mercury and nitrogen. It may be noted parenthetically that wherever possible a direct comparison with the spectrum of hydrogen should be used in measurements between 2000 and 1000 A.U.

McLennan,[9] in collaboration with his students, has measured both the arc and spark spectra of a considerable number of substances. He has employed both prism and grating instruments and with the latter he has pushed his results to the neighborhood of 500 A.U. His researches have emphasized the importance of the suppression of water vapor in the spectroscope; to this end he has added ample drying tubes to his apparatus. It is particularly interesting to note that he has succeeded in obtaining radiations down to the neighborhood of 1020 A.U. through an atmosphere of helium over two meters long at a pressure of 29 cm., thus confirming the transparency of the gas in the Schumann region.

His most recent work revives the discussion as to the existence of the series in helium corresponding to the formula $V=4N\left(\frac{1}{2^2}-\frac{1}{m^2}\right)$. I have presented[10] some evidence for the existence of the two first mem-

[7] *Astrophy. Jour.*, 40, p. 377, 1914.

[8] *Jour. d. Phy. et le Radium*, 2, p. 229, 1921.

[9] Proc. Roy. Soc., 95, p. 258, 95, p. 316, 1919; 98, pp. 95-123, 1920.

[10] SCIENCE, 50 p. 481, 1919.

bers, but I must confess that I am not altogether satisfied with its validity. As to the members of higher order adequate proof of their existence seems to be quite lacking. The crux of the whole matter lies in the fact that to produce radiations of sufficiently short wave length a violent disruptive discharge must be employed which introduces impurities torn from the discharge tube and its electrodes. No matter how carefully the gas is treated the lines due to these impurities furnish a constant source of confusion which must never be overlooked. In spite of the fascinating possibilities conjured up by the work of Rutherford on atomic disintegration, I am of the opinion that but three lines can be ascribed to the spectrum of helium in the Schumann region with any certainty. Of these two lie near 1640 and 1215 A.U. and are by no means above suspicion. The origin of the third at 585 discovered by Fricke[11] and the speaker last year is much more to be relied upon. This last radiation possesses the added importance of showing a direct numerical relation with the radiation potential of helium.

I have said that interest in our subject is spreading. As evidence I present some very recent results obtained on the Pacific Coast by J. T. Hopfield. He has devised a method of studying the emission spectra of gases which are opaque in the Schumann region without the use of a window, the transparent gas which fills the body of the spectroscope and the substance under examination being kept separate by gas currents suitably directed. One of his most striking results relates to the spectrum of oxygen; he not only finds a number of lines throughout the Schumann region which he attributes to this element, but he has also discovered that radiations between wavelengths 1336 and 990 may be photographed even through a column of oxygen a meter long and at a pressure of about 0.4 mm. This result confirms and extends my observations on the absorption band of this gas. Finally, he appears to have discovered an improved process for the manufacture of Schumann plates.

[11] *Phil. Mag.*, 41, May, 1921.

By far the most important contribution to the subject has been made by Millikan.[12] Ably seconded by his students, Sawyer and Bowen, he has not only succeeded in extending the spectrum to the neighborhood of 150 A.U. but also by the study of the radiations in this region he has established a connection between light diffracted by a grating and those shorter wavelengths known as X-rays. Rightly conjecturing that the production of vibrations of the highest frequency depends as much on the intensity of the electric field at the source as upon the substance of the radiator, he has employed a minute high potential spark in the best obtainable vacuum. With this arrangement he has investigated the spectra of a number of substances including carbon, zinc, iron, sodium, magnesium and aluminium and has measured many of their lines.

It is a curious fact that many substances produce spectra of striking similarity in the extreme ultra-violet when stimulated by the high potential spark or even when exposed to a disruptive discharge in a vacuum tube. The lines of the spectrum obtained from helium, for example, are nearly all common to the spectra of carbon and of lithium, while aluminium, magnesium and iron, etc., have identical spectra between 1000 and 250 A.U. The presence of a common impurity furnishes the most conservative explanation for this striking phenomenon, though those inclined to speculation may turn a longing eye toward atomic disintegration. Millikan[13] has shown that oxygen is probably the impurity in question.

Fabry[14] has recently emphasized the fact that this region of roughly 150 A.U. between the limit as set by Millikan's experiments and X-rays capable of analysis by a crystal is one of the most interesting in the whole spectrum. He points out that here the absorption of many substances should pass through a maximum and then decrease; here metals begin to manifest their high reflective power and here the phenomena of refraction will appear,

[12] *Astrophy. Jour.*, 52, 47, 1920; 52, 286, 1920; 53, 150, 1921.

[13] Proc. Nat. Acad., 7, p. 289, 1921.

[14] Journal Franklin Institute, p. 227, 1921.

though probably masked by absorption. The exploration of this region by methods not strictly spectroscopic lies beyond the scope of this paper but the subject is so fascinating that I cannot resist a brief digression.

The production and study of very soft X-rays has occupied the attention of many investigators here, in England and on the continent. One of the researches typical of the early development of the subject was that of Sir J. J. Thomson[15] in 1914; one of the more recent is that of Halweck.[16] As the method of this second investigator seems to trace a rather direct path across the frontier of the extreme ultra-violet it merits our attention.

Halweck generated his soft X-rays in a Coolidge tube of special form separated from an ionisation chamber destined to measure the absorption cofficients of the radiations by an extremely thin window of celluloid. He observes that the absorption coefficient of gases increases with wavelength between 40 A.U. and 100 A.U. following an exponential law similar to that observed by Owen for ordinary X-rays. For celluloid the coefficient at first follows the same law, then increases less and less rapidly, passes through a maximum near 320 A.U. and diminishes toward the ultra-violet. This work is of particular interest since it traces a physical property of a solid, its absorption, through the "no man's land" in question. All estimates of wave length are obtained from the potential difference in the tube and the use of the relation $Ve = hv$.

Holweck finds that a film of celluloid a quarter of a micron thick transmits about twenty per cent. near 1000 A.U., while but three per cent. will pass at the maximum of absorption, this result is of some practical importance to the spectroscopist. Miss Laird[17] has also made a preliminary investigation on the transmission of thin membranes.

The study of radiation and ionisation potentials affords another means of bridging the gap between optical spectra and X-rays. Begun by Franck and Hertz, and continued by many investigators here and abroad with results of such fundamental importance, work in this field has led Mohler and Foote[18] to the discovery of characteristic soft X-rays produced by arcs in vapor. They interpret their results to mean that the critical potentials which they have measured correspond to the first L absorption lines of X-ray spectra of the substances in question: for if the square roots of the frequencies, computed from these potentials, be plotted on a Moseley diagram, the points will be very nearly on a continuation of the straight line typical of the L X-ray spectra of the heavier elements. The longest wavelength they have measured in the L series is for sodium, 353 A.U., magnesium yielding 268, and phosphorus 98. A critical potential for potassium is interpreted as an M series limit with a wavelength of 536 A.U.

When we return to purely spectroscopic investigation we find that the most striking results have been recently obtained by Millikan.[19] In an address before the National Academy, in April, he reports the discovery of certain lines of aluminium, magnesium and sodium at 144.3, 232.2, and 372.2 A.U., respectively, which he identifies as the $L\alpha$ lines of the X-ray spectra of these elements. The square roots of the corresponding frequencies lie very nearly on the straight line connecting $L\alpha$ frequencies and atomic number on the Moseley diagram. The wavelength of the $L\alpha$ line for sodium is in qualitative agreement with the value found by Foote and Mohler; for aluminium and magnesium, however, the case is not so clear. As Duane has pointed out the difficulty arises in this way: it is a fundamental property of X-ray spectra that the $L\alpha$ line lies on the long wavelength side of the L absorption; now the L absorption for aluminium and for magnesium can be accurately calculated; they lie at 173 and 257 respectively, but the $L\alpha$ lines for these substances chosen by Millikan are at 144.3 and 232.2. Thus the values are on the wrong side of the position of absorption.

The spectra of aluminium, magnesium and sodium occupy but a very limited region in

15 *Phil. Mag.*, 28, p. 620, 1914.

16 *Comptis Rendu*, 171, p. 849; 172, p. 439.

17 *Physical Rev.*, 15, 543, 1920.

18 *Jour. Wash. Acad.*, 11, p. 273, 1921. See also Kurth, *Phy. Rev.*, 17, 528, 1921.

19 Proc. Nat. Acad., 7, 289, 1921.

the extreme ultra-violet and there is a considerable blank before their lines reappear in the Schumann territory. It is of interest to inquire if these spectra present that similarity of structure which is a fundamental characteristic of X-ray spectra of the heavier elements.

The nature of modern atomic models might lead one to expect certain rather abrupt changes with decreasing atomic number in the appearance of spectra of elements lighter than Neon. These changes Millikan has observed. He attempts to bring these spectra under the X-ray classification by arbitrarily designating certain lines as the L_α radiation of the corresponding substances. The wisdom of this course seems to me somewhat doubtful, for though there is probably no discontinuity between the mechanism which produces optical spectra and that to which the X-rays owe their origin, yet the structure of spectra of the lighter elements seems to resemble the arrangement of X-rays so little that the same nomenclature cannot be employed in both cases with profit. Even where the radiating mechanism is simple as in hydrogen, there is small advantage in calling the Ritz series a K series or in designating the Balmer series as an L series. However, this objection is only a matter of taste; certainly it in no way detracts from the importance to be attached to Millikan's discovery, for by purely spectroscopic methods he has made a most important advance on the road connecting the region of X-rays with the rest of the spectrum.

Thus we see that the extreme ultra-violet has grown from an obscure corner of spectroscopy to a region of real importance, and that its study has developed from a scientific tour de force into investigations intimately connected with the most fundamental matters.

And now, before I close, let us look back over these thirty years to the man who began it all; *Victor Schumann,* slow, exact, infinitely patient, without any brilliant generalizations in his head but absolutely sound in his conclusions. Perhaps even the atom builder may pause a moment to contemplate him, and may profit by the process.

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REPORT OF THE COMMITTEE[1] ON AN INTERNATIONAL AUXILIARY LANGUAGE ACCEPTED BY THE COUNCIL AT TORONTO, DECEMBER 29, 1921

THE present report makes no attempt to discuss what might be the detailed requirements of an international auxiliary language, nor even to consider alternative solutions already suggested. The committee has interpreted its immediate function as in no sense that of a judge to pass on such matters or even to assemble them for critical review at present, but it aims simply to present herein as concise and constructive a view as possible of the present state of public interest in the problem and to recommend what should be the attitude and activities of the association with respect to serious studies in this whole field, leaving it entirely to the results of such studies, if undertaken, to speak for themselves.

The subject of international language is an old one and a great deal of effort has already been expended upon it, but chiefly by individuals or by organizations formed purely for this purpose. It is only in the last few years that there has been any general movement on the part of governmental, scientific or academic bodies to take the subject seriously and follow it systematically.

The present organized movement in this direction may conveniently be considered as dating from the adoption by the International Research Council in July, 1919, at Brussels, of the following resolutions:

(*a*) That the International Research Council appoint a committee to investigate and report to it the present status and possible outlook of the

[1] Authorized by the Council at St. Louis, December, 1919, and appointed April, 1921: S. W. Stratton (chairman), director, United States Bureau of Standards; Carl L. Alsberg, director, Food Research Institute, Stanford University; V. A. C. Henmon, professor of education and director of School of Education, University of Wisconsin; John C. Merriam, president, Carnegie Institution of Washington; C. E. Seashore, professor of psychology and dean of the Graduate College, University of Iowa.